THE PREVENTION OF DISTORTION IN STEEL DURING HEAT TREATMENT.

Paper presented to the Institution, Luton, Bedford, and District Section, by W. Brazenall.

AS an introduction to this paper on the Prevention of Distortion in Steel during Heat Treatment, it is advisable to give a brief technical outline of the characteristic effects of heat treatment.

What is heat treatment ? Heat treatment consists of the heating of steel to a pre-determined temperature and a cooling from such temperature, in some pre-determined manner, to alter the physical properties of the steel under treatment. In the heating to such a temperature, there are three critical points : AC1, AC2, and AC3, and in the cooling from such temperatures, the corresponding points : AR1, AR2, and AR3. In order to get these critical points quite clear, it is necessary to divide steel into its separate classes.

Steel is an alloy, the essential chemical constituents of which are carbon and iron. The carbon content of steel, with a few exceptions, has the greatest influence on the three critical points. (It is not intended at this portion of the paper to take into consideration the effect of other alloys, such as nickel, chrome, tungsten, etc.). Taking steel with its constituents of carbon and iron, it is divided into three classes, namely, hypo-eutectoid, eutectoid, and hyper-eutectoid.

Eutectoid steel has a carbon content of .9 per cent., which is a saturated solution of carbon, consisting entirely of Pearlite. This carbon ratio is known as the eutectoid one. (Pearlite consists of inter-stratified layers of Ferrite and Cementite. The chemical formula being $21FE+FE_3C$). The eutectoid ratio of iron to carbon, therefore, is a ratio of carbon (Cementite) sufficient to stratify with all the iron (Ferrite) and leave no excess of free Ferrite or Cementite.

Hypo-eutectoid steel has a carbon content lower than the eutectoid ratio and consists of a definite amount of Pearlite, varying according to the carbon content. The balance being free Ferrite.

Hyper-eutectoid steel has a carbon content higher than the eutectoid ratio and therefore there is insufficient Ferrite to inter-stratify with all the Cementite, so this class of steel consists of Pearlite, and an excess of free carbon, that is Cementite.

Having thus classified steel, we pass on to the effect of heating such steels, through their respective critical points. What are these

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critical points? They are temperatures at which definite structural changes take place, whilst the steel is in a solid condition.

During the heating of steel, practically no change occurs before the AC1 point is reached . This AC1 point is the lower critical point and will be referred to as such throughout the rest of this paper.

In passing through this lower critical point, the nature and structure of Pearlite is changed into a new constituent, namely, Austenite. The excess Ferrite, however, remains unchanged. To make this point clear we will liken Pearlite to ice (Cementite) stratified with layers of salt (Ferrite). The ice does not commence to dissolve the salt until it reaches a certain temperature, and alters from ice into water (Austenite). This temperature can be compared with the lower critical point of steel, except that steel, when changing from a Pearlite to Austenitic structure, remains solid.

This new constituent Austenite, which has been born at this lower critical point, possesses a great absorbent power, and just as water (Austenite) will dissolve more salt (Ferrite), with an increase in temperature, so will Austenite with an increase in temperature, absorb the free Ferrite, until a temperature above the AC3 point is attained (hereinafter referred to as the upper critical point), all the excess Ferrite is then absorbed by the Austenite. Steel in this state is what is technically termed a "solid solution."

No reference has yet been made to the AC2 point. This, however, is the temperature at which the Austenite has dissolved a sufficient quantity of free Ferrite, to alter the magnetic quantities of steel. It is the temperature at which steel becomes non-magnetic.

As the carbon content of steel increases, the upper critical point of the steel decreases, until it joins the AC2 point. The carbon content, where this merge occurs, is between .4 and .5 per cent., and with a further increase of carbon up to the eutectoid ratio, i.e., .90 per cent., the upper critical, AC2, and lower critical points all merge into a common temperature. This steel containing only Pearlite, turns into a solid solution of Austenite at the lower critical range, and there being no free Ferrite to absorb, this lower critical point must also be its upper critical point.

Heat treatment begins with the initial heating of the ingot prior to forging. It is at this stage, and also during the subsequent rolling or forging operations, where one of the most prolific causes of distortion can originate, namely, local strains and stresses, set up in metal during the rolling or forging process. Thus, the first step to take, is to ensure that these strains and stresses are released before final heat treatment. Unless this is done, they will be released during the heat treatment of such steel, and it is practically impossible—in fact one might say absolutely impossible—to heat treat any steel which has not had such strains released, without experiencing distortion. It is, therefore, of primary importance, that any steel

which has subsequently to be heat treated, shall come into the hands of the users, with the rolling and forging or any other local strains released. This can only be done by annealing. Annealing, in its commercial application, may have for its purpose any of the following aims :

(1) To soften the steel.
(2) To meet certain physical specifications.
(3) To relieve any internal or local strains or stresses caused by the rolling or forging operations.
(4) To obtain the maximum grain refinement in combination with ductility.

Depending upon the result desired, annealing consists of two well defined and co-ordinated phases, the heating phase and the cooling phase, to and from some pre-determined temperature, although not necessarily a temperature over the upper critical point, to produce the desired results (1) and (2), i.e., to soften the steel or to meet certain physical tests, but true annealing requires a heating to above the upper critical point of the steel, followed by suitable cooling. Regardless of the phase being considered in this process, whether heat absorption or heat emission, each is co-related with the factors of time and temperature.

The temperature to which the steel is to be heated is that at which the desired change in grain size, micro-constituents, and strain release will take place, and the range of temperature of the cooling phase is defined by the transformation range of the steel.

The time element in the heating phase, is one of duration to saturation above the upper critical point, and is dependent upon the mass and surface of the material under treatment. The time element in the cooling phase, is the rate of cooling through the critical range between the upper and lower critical points, and is determined by the result desired, the mass and surfaces of the steel under treatment.

Looking at this question of annealing with a view to removing all local stresses and strains, set up by rolling, forging, or other elaborate operations, to ensure the minimum of movement or distortion in subsequent heat treatment, the annealer should know the history of the steel under treatment, especially the temperature at which the steel has been heated in the rolling or forging operation, and particularly the finishing heat of the last pass through the rolls or hammer, for this has a great bearing upon the structure and strains set up by this operation. The greater the strains, the more care has to be taken in the annealing process. What, therefore, must be the heating phase, cooling phase, and the duration of soaking to obtain full stress release ?

Taking the heating phase, the steel should be heated slowly and uniformly, in order that the release of any strains shall not

cause warpage. The temperature to be attained, is that of one above the upper critical point. This critical point, as already shown, depends principally upon the carbon content of the steel. As the transformation at this critical point does not occur suddenly, it is usual to take a range of about 50 degrees C. to 70 degrees C. over this point as the annealing temperature, thus ensuring that the steel is in a solid solution, with all stresses released.

The best practice, wherever possible, is to attain during the annealing process a temperature higher than any subsequent temperature to which the steel will eventually be heated, in further heat treatment. In respect to the time factor for soaking above the upper critical point, it is the length of time necessary to soak to saturation value, and depends upon the mass and condition of the material. If the material has been badly strained, a longer soaking period will be necessary to obtain the desired strain release. Hence, the annealer, as stated before, must know something of the history of the steel under treatment, before he determines the temperature, and time factor for soaking, in respect to strain release.

If the steel in annealing, has been badly warped, or bent through improper heat application, it should *not* be cold straightened, as this process may set up local stresses and strains far in excess of the original forging strains. Should it be impossible to utilise such bars, without cold straightening, they should be hot straightened and, if necessary, re-annealed. It has been known for a three per cent. nickel oil hardened and tempered steel bar, five inches diameter, which had been cold straightened after treatment, to spring $\frac{3}{4}$ inch out of centre, following the development of slight heat on being rough machined.

Thus, the preliminary step to be taken in the prevention of distortion, during heat treatment, is to ensure that the steel has had all local strains and stresses removed, and the maximum grain refinement achieved by a proper annealing treatment.

We now pass on to the second step in the history of heat treated steel, namely, the hardening. This consists of heating to saturation at a temperature above the upper critical point, and cooling rapidly from such a temperature.

Heating. The essential function of heating to above the upper critical point of steel in hardening is :

(1) To obtain the best refinement.

(2) To obtain the formation of the *hard constituents of the steel*, and having obtained this result, to hold the steel in this condition by rapid cooling, in some quenching medium.

In this operation of heating and rapid cooling, it is essential, if distortion is to be avoided, that the greatest degree of uniformity possible be obtained.

The temperature attained in the heating, and degree of saturation, is of the utmost importance, as correctly hardened steel should show no trace of the original coarse grain, net work, or unabsorbed Ferrite structure peculiar to untreated steel. Hence, if the structure of the steel has not been suitably changed or developed in the heating, and soaking above the upper critical point, most assuredly, it will not be altered for the better by subsequent quenching. Quenching at the most, can only retain the characteristics which have been developed in the heating.

As in annealing, the steel under treatment must be heated slowly and uniformly to ensure a uniformly heated product. The first consideration, therefore, before applying heat to such a product must necessarily be the mass to be heated, and the surfaces exposed to the heat. These determine the rate and manner of heating, together with the time necessary for saturation.

It has been shown that in the annealing of steel, it must *not* be put in a hot furnace, if warpage is to be avoided. It must naturally be of greater importance for this condition to be observed, in the heating for hardening, when the products under treatment are complicated or asymmetrical in shape. If a cold component be placed in a furnace of a temperature above its upper critical point, warpage and distortion must take place, and in many cases, such distortion (due to unequal expansion) develops immediately into a crack, technically known as a clink.

It is fully realised, that in mass production, it is impossible in many cases to start each batch of components in a cold furnace; it is essential, therefore, that a pre-heating furnace should be used, and the components under treatment should be thoroughly and uniformly soaked in this furnace before being transferred to the hardening furnace.

This hardening furnace should never be at a higher temperature than that required for the hardening of the steel under treatment, otherwise any thin portions, sharp corners, etc., would take the heat much more quickly and in greater degree than the main body of the component, and these parts would be decarburised. Such decarburisation greatly decreases the efficiency of the material in service, and in cases of very severe over-heating or burning, the service efficiency one would obtain from such steel would be practically nil.

The ideal temperature to which the steel should be heated in the hardening process is one just over the upper critical point and under the annealing temperature. Just as the annealer should know the previous treatment of the steel so should the hardener. It has been shown that the annealing temperature range should be 50 degrees C. to 70 degrees C. above the upper critical point, hence the hardening temperature range should be 25 degrees C.

to 50 degrees C. above the upper critical point. There are some exceptions to this annealing-hardening temperature relationship, notably, high speed steel and air hardening alloy steel.

In respect to the type of furnace to be used it is impracticable to recommend any particular kind, owing to the vast field of requirements to be covered, but whether fuel fired, electrically heated, molten salt baths, or hot air, the shape and mass of the material under treatment should be carefully studied with a view to ensuring a slowly and uniformly heated product of saturation value to the desired temperature.

A uniform furnace temperature does not necessarily mean that this uniformity of heat saturation is obtained, and steps must be taken to ascertain this important factor of a uniformly heated product of saturation value, before quenching. It is only by obtaining uniformity in the heating process that distortion can be prevented or, in other words, the material should be heated so that the time factor and temperature are so co-related that equal expansion of the mass and surfaces of the steel is ensured. If there were no such thing as unequal expansion there would be no such thing as distortion in the heating process.

Having obtained by the heating the refinement and formation of the hard constituents of the material, it is necessary in order to hold the steel in this condition, to cool rapidly by some predetermined methods of quenching, varying according to the chemical composition of the material.

Just as in the case of heat absorption, so in the case of heat emission, the factor of uniformity must be observed. Hence the mass and surfaces of the material determine the manner in which the component should be quenched.

There is no hard and fast rule properly relevant to the manner of quenching. Usually the material should be quenched vertically with its greatest length (a notable exception being half-rounds). Hollow cylindrical shapes should be quenched with the bore vertical, obviously in some instances one or the other of these conditions cannot be observed, and the procedure must be left to the discretion of the hardener. In all cases the material should be kept in motion in the quenching medium, and should not be withdrawn until full uniform heat emission has been achieved.

Every component destined for the hardening operation should be critically considered in relation to aspects of pattern, size, distribution of weight, etc., with the view of ensuring a manner of quenching which will provide *maximum uniformity* of heat emission.

This consideration will embody such questions as the plugging of all blind holes with fire-clay or some such material, also any holes which leave a comparatively small mass of material, between

the edges and the outer or inner surfaces of the component. If such plugging has not been done, the quenching medium cools these thin portions much more rapidly than the bulk of the material, and distortion takes place, in many cases to such an extent as to cause fracture. Uniform heat in the furnace does not necessarily mean a uniform heat at the moment of quenching and it is at this latter period that the prevailing factor, the human one, predominates, more than at any other period in the heat treatment of steel. Unless there is this uniformity at the moment of quenching irregular cooling will take place and lead to distortion owing to unequal contraction. Just as in the case of expansion in heating so in contraction cooling, if there were no such thing as unequal contraction, the problem of distortion during quenching would be a negligible one.

Great stress has advisedly been laid on the necessity of heating to saturation value. If this is not done internal distortion will take place upon quenching, even to the extent of what is known as an internal hardening burst. There are no doubt members of the Institution of Production Engineers who will recall with mixed feelings, and perhaps lurid language, how " many a time and oft " the hardening of some specially intricate component, a master—a gauge—a delicate cutting tool, which has been carefully watched and lovingly tended from its very birth in the ingot, has brought the flush of triumph to the brow on realisation of successful completion of a difficult job. But on the morrow the masterpiece lies cracked and useless on the bench. If it has been a cold night the frost is blamed, but mostly the failure is due to either insufficient soaking in heating, or uneven contraction in cooling, resulting in an internal hardening burst. Admittedly frost will tend to expedite the development of such a burst, but even if no crack, actually develops, the service efficiency of any tool possessing a latent defect of the kind indicated can be no more than very doubtful.

The one essential factor in the prevention of distortion in the hardening process may be expressed by the word " Uniformity." Uniformity in heating, uniformity in soaking to saturation value, uniformity in quenching.

In the hardening of steel, stresses known as hardening strains are set up, and these are removed by a tempering process. This consists of heating the steel to some temperature under the lower critical point, varying according to the chemical composition. The method of cooling from such temperature, is dependent upon the chemical constituents of the steel.

In the tempering process, as in hardening, in the application, and emission of heat, the maximum uniformity must be obtained, particularly when such steel as nickel chrome and other alloy steels which have a comparatively high tempering point, are under treatment.

The question of machining strains and their relation to distortion, has yet to be considered. These strains are set up locally when excessive and rough machining is done. It must be left to the judgment of the operator to decide whether it is necessary to normalise or re-anneal the material in the rough machined state before final machining, in order to remove these strains, the factors to be taken into consideration are the chemical composition of the steel, the shape of the material, the nature of the machining, and the degree of accuracy required.

Finally, there is the question of the chemical and physical composition of the steels, in respect to the question of distortion. For this purpose it is intended to take for an example a broach 36 inches long, which is required to cut serrations of the shape of a triangle, the apex of which has an acute angle of 60 degrees. The two steels which manufacturers appear to favour for this class of tool are case-hardening steel and high-speed steel. Is either of these steels the ideal ?

For instance, case-hardening steel. This steel was never intended by the metallurgist to be used as a cutting medium, but to meet the requirements where a hard-wearing surface, together with a tough core, is called for. Further, great care would have to be taken in the carburising of a broach, made of this steel, in order to avoid free Cementite, especially at the most important point, the apex of the tooth. Even if carburising by the Cyanide process, where it is claimed that the carbon penetration is less likely to result in a case containing free Cementite, than in a compound carburised case, the possibility of the tooth at the apex, being entirely free from Cementite is very remote—free Cementite being very brittle would cause the case to snip or flake, when the broach was put into service. The risk of distortion in the heating and cooling operations has been shown, and here is a tool of intricate and delicate shape which, if made from case-hardening steel would require three heatings, one slow cooling, and two quenchings. These reasons alone, apart from any question of efficiency should lead one to think very deeply before making a broach of case-hardening steel.

In respect to high-speed steel, a broach of this design made of this steel, was submitted to me for an independent opinion after it had failed in service. The nature of the failure was the stripping of the teeth from the body of the broach and was, in the hardener's opinion, due to faulty steel. The steel maker claimed that there was nothing wrong with the steel, and considered that the failure was due to faulty heat treatment.

The result of my investigation is embodied in the following report :

" A portion of the body of the broach, together with one of the

teeth, was polished and etched longitudinally and transversely to the grain of the material. The microscopic examination shows no abnormal flaws or segregations, but whilst the tooth itself shows a perfect structure for a hardened high-speed steel the main body of the broach shows a structure indicating that the broach has not been soaked to saturation—in the heating, prior to quenching, in the hardening process. The structure and orientation at the portion where the failure has occurred, is such, that in my opinion, minute internal bursts have occurred in the hardening, and these bursts have developed in such a manner as to cause failure, upon the broach being put into service."

The point then raised by the hardener was this: *How can* one soak such a broach at the heat of 1,300 degrees C. (the steel maker's instructions) to saturation value without burning the teeth? Well, it cannot be done, and that sums up in half-a-dozen words the reason why high speed-steel is not the ideal steel for this purpose.

The reason high-speed steel is used for general cutting purposes is because of its property of red hardness. Is this a property a broach must have? Surely not, or how is it a carburised surface of 90 degrees C. will do the work. What steel then, would be considered ideal for a broach of this kind?

First, it should be an oil hardening steel and be capable of being hardened at a heat below its annealing temperature. In view of this and also of the physical requirements, the steel will have to be hyper-eutectoid, so some alloys will have to be introduced to combine with the excess Cementite, therefore a sufficient percentage of Tungsten to combine with the excess carbon or Cementite should be added.

We have now a hyper-eutectoid, Tungsten alloyed steel, which can be hardened at a temperature of 900 degrees C., but this can be improved upon. By the addition of chromium or manganese in the correct percentage, the upper critical point of this steel can be lowered at least 100 degrees C.

Here, then, is a steel, hyper-eutectoid in nature, alloyed with tungsten and chromium, which can be annealed and soaked to saturation at a temperature of 880 degrees C., and which can be hardened at a temperature of 820 degrees C.

It needs no further words of mine to show that a broach made from this steel can be soaked to saturation in the heating prior to quenching, with all fear of burning the teeth eliminated. Thus, one is able to ensure a uniformly heated tool at the moment of quenching.

There are the three steels: case-hardening steel, with its complicated treatment; high-speed steel, with the risk of internal hardening bursts; and this hyper-eutectoid chromium, tungsten alloy steel. Bearing in mind this all important question of distortion, which steel will you use?

In conclusion, briefly summed up, the Prevention of Distortion in Heat Treatment depends upon :—

(1) Removal of all forging strains and stress by true annealing.
(2) Removal of machining strains (where excessive rough machining occurs) this being done by annealing or normalising.
(3) Uniformity in Heating.
(4) Uniformity in quenching.

Before concluding my talk—the first I have had the honour of giving to the members of this great Institution of Production Engineers—may I, as a very humble but very enthusiastic metallurgist, make an earnest appeal for yet closer co-operation and understanding between the men who make the steel and the men who shape it. Purely practical and prosaic though his purpose in life may seem to be, the metallurgist is nevertheless an idealist—his ideal being to produce a material stronger than the strongest steel and lighter than the flimsiest gossamer.

You production engineers also have your ideals—maybe one of them is to take the ideal material of the metallurgist and from it to construct the, as yet undreamed of, universal aerial transport of the future. Is it too fanciful to predict that, hand in hand, the metallurgist and the production engineer can lead humanity to the very stars ?

Discussion.

Mr. Pudge said that he would like to ask Mr. Brazenall a question with regard to high carbon chrome steel lending itself to the manufacture of broaches, etc. One can get uniform heat treatment and saturation, and also uniform quenching, but is it not necessary to protect the sharp edges in some way? Otherwise it would appear that such portions are liable to burn.

Mr. Brazenall replied that in the case of a broach with an acute angle of 60 degrees it was usual to heat in a compound of some kind, such as ordinary charcoal. No bone "dust" should be used on account of the penetration of the carbon.

Mr. Whiting asked Mr. Brazenall if he considered that work in motion during quenching is in danger of distortion. He also asked Mr. Brazenall to explain why it was laid down that all quenching should be done on a rising temperature instead of a falling temperature. Bearing this principle in mind, he considered that the hardener should be closely instructed to see that the temperature is rising rather than falling to the required heat.

Mr. Brazenall said, with regard to quenching on a rising heat, that he failed to see the necessity for this question as if uniformity is maintained during heating, the furnace cannot possibly be at a higher temperature than that required for hardening. With regard to the question of work being in motion during quenching, he considered it preferable to use a motion vat, such as a spray bath, where one can absolutely guarantee that there is a good flush of quenching medium, rather than to keep the component in motion.

Mr. Mills asked Mr. Brazenall why, generally speaking, high carbon steel distorts much more than low carbon steel. Also, why is it that one frequently finds difficulty in machining certain parts which have passed well known hardness tests such as Brinell, etc. It is quite a usual occurrence satisfactorily to machine components for some time without trouble, and then we may suddenly come up against a batch of the same components which have produced facsimile readings on Brinell test, which cause rather annoying difficulties during machining. He had experienced some difficulty in machining chrome carbon steel. This difficulty was stated to be due to the condition of the carbon, which was found to be breakable and unmachinable. He asked Mr. Brazenall if he could explain how that condition was caused and the best way to eliminate it.

Mr. Brazenall assumed that by "high carbon steels," Mr. Mills was referring to steels above the eutectoid ratio. It has been shown that in order to avoid distortion, it is necessary to get all the steel into the solid solution before quenching. The actual procedure is to

raise the temperature of the steel above its AC3 point, which means that the Cementite is out of solution, and then, on cooling down, this Cementite, which is solid, is bombarded by the remainder of the steel which is in the solution. Referring to the question of excessive hardness in some classes of steel, if this trouble is uniform, the only conclusion he could come to was that this is probably due to rolling slightly oversize, and the process of getting the steel down to size brought it below the AC1 point. This will result in a hard polished scale, which simply tears or grinds away the cutting edge of the tool. Regarding carbon chrome steels, i.e., one per cent. carbon, one per cent. chrome, ball bearing steel, etc., there are many different opinions in Sheffield on this subject, and he did not feel inclined to dwell too largely on this question at this stage, bearing in mind the lengthy discussion which might result, particularly as the experts in Sheffield were at the moment in disagreement.

Mr. Carrier asked Mr. Mills if he would clarify his question as regards ball bearing steel.

Mr. Mills replied that in connection with the point which he raised as regards high carbon chrome steel of the ball bearing quality, it has been his experience to strike a batch of steel which has been analysed and passed as satisfactory for production. The difficulty in machining has been due to the structure being in a spheroidal condition. Consequently, in attempting to machine it, the radii of the balls prevents the tools getting hold of them. That is the theory, and there used to be a heat treatment which resulted in a more normal condition of the bearings as regards shape.

Mr. Carrier stated that the structure described by Mr. Mills was the ideal structure for high carbon chrome steel such as is used for ball bearings. Special care is taken in the annealing process to ensure that the structure is completely spheroidised when the steel has a Brinell hardness of 180 and machines comparatively easily. If not annealed correctly some lamellar Pearlite will remain and this may increase the Brinell hardness up to 300 and will certainly give rise to machinery troubles causing the tools to dull rapidly. Hard spots in the material are sure to be encountered if lamellar Pearlite is present. To prevent distortion in hardening it is imperative that the whole of the structure is in the granular or spheroidised condition before hardening. This type of structure is also desirable in the finished ball race to obtain maximum wear resisting properties. With regard to the quenching of steel it has been stated that the quenching fluid should be in motion. To obtain uniform and rapid quenching it is not only necessary for the solution to be in a state of agitation but the quenched pieces must also be moving. This is specially important when quenching several objects at a time, otherwise you might have two faces of hot metal in contact thus retarding the rate of cooling due to the solution not reaching the

portions in contact and in consequence soft spots—possibly cracks—would result.

Mr. Brazenall stated that as regards heating a broach in a salt bath, there is a great deal of experimental work going on in Sheffield at the present time on the decarburisation of surfaces heated in salt baths, and until the metallurgists can bring forward a steel to make salt baths which will withstand a temperature of 1,300 degrees C., he did not see how it could be possible from a production point of view to introduce such a process.

Mr. Carrier stated that his company were at the moment heat treating high speed steel—particularly taps—in salt baths without any difficulty. This work was going on continually on taps which were ground all over.

Mr. Brazenall said that to heat treat taps up to one foot in length was a slightly different proposition to that of the 36 inch broach referred to in his paper; and he added that generally speaking, he did not consider it a practical proposition to make taps from high speed steel.

Mr. Harper referred to the machining of some air hardened stampings—bevel gears. He stated that these gears were satisfactorily turned, but on reaching the gear cutting operation, the material showed definite signs of hard spots, and he asked Mr. Brazenall if he could give an explanation for this. Another point was the annealing of machined parts and then of normalising, and he asked Mr. Brazenall if he were to understand that there is no difference between these two forms of heat treatment.

Mr. Brazenall stated that the question of hard spots on gear wheels had no bearing on this lecture, and he did not, therefore, propose to deal with this problem. As regards Mr. Harper's second question, Mr. Brazenall stated that he certainly did not give the impression that normalising and annealing were one and the same. Annealing consists of heating up to the upper critical point and soaking to such temperature, and a cooling phase between the upper and lower critical points. To normalise is to raise the temperature above the upper critical point (no soaking), and cooling from that temperature.

Mr. Sjögren asked Mr. Brazenall if it is possible to add anything to the salt bath to prevent decarburising.

Mr. Brazenall stated that experiments have not yet reached the stage whereby it is possible completely to prevent decarburisation in the salt bath, but one of the leading firms in the country are experimenting at the present time with a view to preventing this trouble. Up to now, however, it is fully realised that there is a certain amount of decarburisation on some classes of steel.

Mr. R. Broomhead stated that having had a fair amount of heat treatment experience, he considered it impossible to prevent

distortion, and the results that one gets from experimenting with steels and measuring tackle is not only extraordinary, but very contradictory. As an instance, take a Sheffield made high class carbon steel—oil hardening—in its raw state ; turn it, create all the machining strains you like, and then measure it. Upon normalising to release the machine strains, give it the heat treatment specified by the metallurgist. Assuming this to be a dimension of 14 threads per inch, you will probably find that after heat treatment the pitch varies by say plus or minus .0005 inch. This is distortion all the same, so much so that it is not good enough. Then take another piece of steel off the same bar. Turn it in precisely the same way, and when you have created all the machining strains and rough screwed it, normalise it. Continue with the job, finish screw, and pass it on to the hardener, who shall carry out the same process of heat treatment as before, and on measuring, it may be found that the dimension varies anything between plus and minus .002 inch in pitch. This is a very contradictory state of affairs, and these defects happen over and over again. Take a two inch screwed ring, normalise if you like, after relieving all the machining strains, and measure up again, and note the result.

One of the questioners had asked why it was that high carbon steel distorts more than low carbon steel. This seemed most extraordinary, because if you take a two per cent. or three per cent. nickel steel, screw, and measure it, and then take a high carbon steel one, you get just the contrary to what the questioner was getting at.

During his lecture, Mr. Brazenall told us about the man who makes up a wonderful die or some other elaborate piece of equipment, only to find that after completing it, it is discovered to be cracked. Such conditions certainly used to exist, but if the production engineer will only follow out the instructions given to him by the metallurgist, and heat treat accordingly, then he won't go far wrong. With regard to broaches—particularly high speed steel broaches—he would like Mr. Brazenall to remember that to-day we are living in a grinding age. For instance, 60.5 threads per inch are actually being ground from the solid ; so that this trouble of decarburisation on corners of broaches, although 36 inches long, is rather exaggerated, as it is only the last few notches that do anything that really matters ; therefore, it should be quite easy to grind broaches to-day. Probably the production of high speed steel broaches has been due to the introduction of the hydraulic broaching machine.

Mr. Brazenall agreed that it is impossible to prevent distortion during heat treatment, but he stated that he thought the idea of all of them was to ensure the minimum of " movement " during heat-treatment. This was emphasised throughout the lecture.

Mr. Harper mentioned that Mr. Brazenall had explained the necessity of great care being taken as regards the critical points, and

he asked what the relationship was between these critical points and the effect it has on such articles as gap gauges, i.e., whether the tendency is to contract or expand. For instance, in heat treating two gauges made from the same steel, one opened slightly and the other closed. Definite information on this point would be a great help to anyone making such articles.

Mr. Brazenall replied that he did not think that the temperature had anything at all to do with the point of view of expansion or contraction of the finally hardened object. As long as the temperature is raised above the AC3 point, and full saturation value is achieved, and the same uniformity is observed in the cooling, the " movement " in the two articles should be the same. The fact that one expands whilst the other contracts is either due to not soaking to saturation value, or not obtaining the maximum uniformity of heat emission.

Mr. Ronald (Chairman, Section President) remarked that in the early part of the lecture, reference had been made to some constituents in connection with the steels from which broaches are made. He said that he thought he knew the type of broach referred to, namely the 36-spline standard broach, which was first introduced in 1914. At the time he was instructed to obtain a set of five of these broaches. Difficulty was experienced in obtaining these broaches in this country, and eventually they were obtained from the States, namely, from Messrs. Lapointe. A few months after the receipt of these broaches Messrs. Armstrong-Whitworth started making similar broaches. The Lapointe broaches were made from case-hardening steel .01 C., almost equivalent to S14. These broaches were in operation for ten years, and during that time there was not a single tooth broken in the whole set of five broaches. They were not ground, but planed and hardened, five heat treatments being necessary—that is to say, five times in the furnace.

Mr. Bamford asked Mr. Brazenall if he recommended the use of fixtures for holding components whilst being heat treated, or whether there was a danger of serious distortion in the component at the point of contact with the fixture.

Mr. Brazenall stated that as regards the use of a fixture for holding a component in position when liquid or quenching medium is used, this is so arranged that the component can rotate. With the fixture rigid, and the component rotating whilst quenching, this will certainly set up strains unless absolute uniformity in quenching is maintained. About eighteen months ago, an attempt was made to place on the market a machine for holding long delicate tools—particularly broaches—in position whilst quenching. It had been his experience to see a broach quenched in such a machine. During quenching, the broach kept very straight, and very accurate. However, after broaching six components, the broach bent, and

then broke. Microscopic examination of the break showed that this was due to being held in the quenching fixture by this portion, where distortion had taken place.

MR. SJÖGREN spoke of a rotating fixture for holding camshafts whilst heat treating. He said that this process was being satisfactorily carried out, with no cracking or bending, etc., on these hardened surfaces.

MR. BRAZENALL, speaking of the rotating fixture for camshafts, said that he had actually seen this process in operation, and was very much impressed by the arrangement of it. He wondered what degree of accuracy was required on these camshafts, and whether all the machining stresses were taken into consideration before the rotating fixture was installed. He was of the opinion that the equipment he saw should adequately meet the requirements for the hardening of these camshafts.

MR. RONALD said that he had occasion to make some boring bars about 18 inches long by $\frac{3}{4}$ inch diameter from air hardening steel. These gave considerable trouble due to bending. Difficulty was experienced in straightening for grinding without leaving excessive allowance on them. It was suggested that these be put between centres ; this was tried, with little success, and it was found necessary to widen the grinding limits. He wondered if stresses were being thrown on these boring bars.

MR. BRAZENALL replied that it has been definitely stated that to keep the work in motion, and to have the quenching medium in motion, is the ideal method of hardening. If that is done, no stress is being put on.

MR. B. C. JENKINS spoke of the quenching fixture for camshafts, previously referred to by Mr. Sjögren. He stated that he did not wish to create the impression that this quenching fixture was infallible. In fact, the camshafts are straightened afterwards, with an excess grinding allowance left on them. As regards fixtures such as the Gleason bevel gear quenching machine, he though most people who have used it, will agree that the results obtained when using such fixtures would be impossible to get from any other means. He queried the different methods of forging steel when producing stampings, etc. He wondered whether pressure had anything at all to do with distortion of components afterwards. We are given to understand that proper study of forging processes can to a very great extent eliminate distortion in heat treatment, and if that is so, it would be interesting to know why this trouble is still being experienced.

MR. BRAZENALL, speaking of drop stampings, stated that the direction in which the " drop " is done in relation to the grain of the steel will considerably affect this problem. Also, unless such

stampings are annealed and soaked to saturation above the upper critical point, distortion will take place. Mr. Brazenall added that, so far as was indicated by his personal experience, the annealing of drop stampings was usually assumed to have been satisfactorily carried out provided that no difficulties were encountered in subsequent machining operations. This, however, was quite clearly an erroneous assumption which was probably due to lack of consideration by manufacturers of drop stampings of the very problem they had been discussing that evening—the problem of the movement of steel due to heat treatment.

Mr. Smith stated that he had experienced considerable difficulty in the heat treatment of spring collets, and he understood that this trouble was more or less general throughout the country. He asked Mr. Brazenall if he could give him any idea as to the best heat treatment for spring collets and spring pads. They all knew that they have to be "closed in," and what usually happens after heat treatment, is that they break almost the first time in use.

Mr. Brazenall, as regards the heat treatment of collets and their subsequent breaking, stated that after heat treatment nine times out of ten, the cause of failure is due to holding to the desired size over a mandrel or something similar during heat treatment. Some firms are hardening collets, letting them close up to what extent they like, and on tempering, they open the collets out and then quench from that temperature. It is claimed that many breakages are prevented in this manner.

Mr. Ronald thanked Mr. Brazenall for his very interesting and educative lecture. He stated that the discussion had thrown up some very useful points; one of the finest points Mr. Brazenall made, was his appeal for closer co-operation between manufacturers and users of steel. We certainly do believe in the closest co-operation possible in this respect, as you cannot get the results you want unless you keep in touch with the people who make your steel.

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HEAT TREATMENT.

Papers presented to the Institution, Birmingham Graduate Section, by A. McNab and S. Wood, Graduates.

Paper by A. McNab, Grad.I.P.E.

ORIGINALLY the name of steel was applied to the various combinations of iron and carbon; to-day the use of the name is extended to the ever increasing field of alloy steels. The rapid progress of automobile engineering, aviation, electrical generation, steam turbines, etc., owes much of its success to the development of alloy steels and their subsequent physical properties dependent upon the science of heat treatment. There is not time to-night, to give a complete review of the heat treatment of all the different steels. I have therefore confined my remarks mainly to the carbon group, which I consider will form a useful introduction to the fundamental principles of heat treatment.

The object of heat treatment is to impart certain desired physical properties; these physical properties are produced by the structural changes which occur through the influence of heat at varying temperatures, and by the regulation of the speed of cooling.

The transformations which occur when steel is heated are due to the phenomena called "Allotropy." Carbon is allotropic, i.e., it exists in three states, as diamond, graphite, and charcoal. Allotropic changes are usually accompanied by crystallographic changes and spontaneous absorbtions of heat, on heating and evolutions of heat, on cooling.

When pure iron is cooled from the molten state to atmospheric temperature, and means are used to note its temperature, at all instants, during the cooling, it is found that cooling to a temperature of 909 degrees C., proceeds at a regular speed, but on reaching that temperature slows down or even stops, although the conditions under which the piece is cooling have not changed in any way. After a period of time, cooling continues again in a uniform manner, until 768 degrees C. is reached, where the same arrest of temperature is again observed. At these temperatures, it is evident that something is happening in the iron which is not caused by the means to cool it. It is also evident that whatever does happen requires time to take place. In fact, these evolutions of heat or arrests of temperature, are the result of allotropic transformations within the iron, and

Birmingham, November 29th, 1933.

actually are the changing of Gamma iron (which exists at temperatures above 909 degrees C.) to Beta iron, which exists above 768 degrees C., and from Beta iron to Alpha iron, which exists from 768 degrees C. to atmospheric temperature.

Similarly, when heating iron from atmospheric temperature, arrests in temperature are observed due to absorbtion of heat, when Alpha iron changes to Beta iron, and when Beta iron changes to Gamma iron. Actually, Beta iron only exists in steels below 0.35 per cent. carbon ; above this content, the Alpha iron merges directly into the Gamma state. The temperatures at which these allotropic transformations take place are called critical points, and the temperatures between the critical points are called critical ranges. They are also called decalescence points on heating and recalescence points on cooling. It is due to this phenomena of allotropy, that iron, when alloyed with carbon, provides the various constituents which control the possible physical properties that accrue when the alloy is subjected to heat.

The physical properties depend upon the various structures, which are governed by : (1) The composition of the steel ; (2) The temperature to which it is raised ; (3) The rate of cooling from that temperature.

The composition determines the elements which may be present ; the temperature influences the chemical combinations taking place between the elements present ; and the rate of cooling influences the degree of completeness of the combinations, made possible by the temperature, and consequently influencing the relative physical properties. Each type of steel has its own characteristic temperatures and responds best to those temperatures.

To obtain the maximum results from a steel, it is evident that the critical points must be known. The most essential point is the temperature at which the steel becomes completely in the Gamma state. An increase of carbon lowers the critical range ; this means that the critical point of a 0.25 per cent. steel is approximately 860 degrees C., and a 0.9 per cent. steel approximately 780 degrees C.

There are two main methods of determining these critical points. Steel, at atmospheric temperature, is in the Alpha condition, and is magnetic, that is, it is attracted by a magnet. Beta iron and Gamma iron are non-magnetic, and as Beta iron ceases to exist in a steel of more than 0.35 per cent. C., the merging of the Alpha to the Gamma state is easily observed by the simple magnetic test. The pyrometer, which indicates degrees of heat only, is also used, and is generally coupled to an instrument which plots a graphic record of the rate of heating and cooling ; the pauses, or arrests of temperature are thus definitely recorded. Such a curve will show that the arrests or pauses of temperature which occur on heating are higher than the

corresponding points which occur on cooling ; generally the difference ranges from 20 degrees C. to 40 degrees C. according to the composition.

This lag of temperature is common to all critical changes produced by heat treatment, and is of most importance because of its influence on the rate of decomposition of the structure formed at the upper critical point. Steel is essentially a solid solution of iron and carbon. (*Slides showing various structures were here shown.*)

Having briefly reviewed the various structures which occur when an iron-carbon alloy is subjected to heat, it will be interesting to follow more practically the changes which occur when a steel of known carbon content is treated by general processes of normalizing, hardening, and tempering. Actually, the steel may contain small amounts of manganese, silicon, sulphur, and phosphorus, but for our purpose their slight effect on the changes taking place can be disregarded.

Generally speaking, the finer the crystal size of a material, the greater will be its physical properties.

Normalizing is the process of refining the structure, and relieving any internal strains set up in previous working. If this piece of C. steel (*shown on slide*) is heated to the upper critical point, all crystallisation, however coarse and distorted, is removed and replaced by the finest structure the steel is capable of assuming. What has happened is that the Ferrite and Pearlite have changed their appearance, chemical combination, and crystal size, and merged to form one solid solution, which is Austenite. The fine structure produced can be retained if the steel is allowed to cool slowly ; the Austenite reverts slowly back to the original Ferrite and Pearlite, resulting in the finest and best distributed structure the steel is capable of assuming. It is desirable that the temperature should be maintained for about fifteen minutes and does not exceed the upper critical point by more than 50 degrees C.

Should a steel be heated above the upper critical point and cooled slowly, the crystals begin and continue to increase in size on passing through the critical range until the lower critical point is reached, which is when the Gamma state changes into the Alpha state ; below this point there is no further growth of crystal size.

Should overheating continue for any length of time, the material will partially fuse at the crystal boundaries, permitting the penetration of oxygen, resulting in the formation of a film of oxide between the crystals, and the steel will become " burnt." It will, therefore, be understood that in all normalising operations the careful control of the temperature is of most importance. All processes which aim at the production of greater strength or toughness in a steel involve the process of hardening that steel. No hardening can take place unless the steel is heated to the temperature

at which Austenite is formed. This is the upper critical temperature and is when the steel is in the Gamma state.

If a 0.45 per cent. C. steel is heated to 820 degrees, and suddenly cooled in cold water, it will be practically fully hardened. Fully hardened means that the Austenite is held in solid solution at atmospheric temperature. Actually, in general practice, the decomposition of the Austenite is so rapid that, by normal quenching, *no* Austenite is retained, and the structure, according to the rate of quenching, contains varying proportions of Martensite, Troostite, or Sorbite.

The changing of Austenite to Martensite is accompanied by an increase in volume, and in consequence the steel is in a state of severe strain.

Tempering is the reheating process by which hardened steels are rendered fit for service. The purpose of tempering is to remove hardening strains and to soften and toughen this steel to the desired extent. Tempering is most effective at the lower critical temperature, and if the tempering temperature is above this point all effects of hardening are reduced.

Should an Austenite structure be formed by hardening, tempering transforms the structure to the less hard forms of Martensite, Troostite, Sorbite, and Pearlite, the proportions depending on the composition of the steel, the tempering temperature, and the time at which the temperature is maintained.

The process of hardening is not applied to carbon steels to anything like the same extent as to alloy steels ; some mention of the influence of the alloying elements will be of interest. Practically all carbon steels contain silicon and manganese, but in such small amounts that they have no special effect on the general physical properties of the steel. When increased, however, both silicon and manganese produce steels which have entirely different properties.

Nickel, chromium, manganese, molybdenum, vanadium and, tungsten are the principle alloying metals used in general engineering practice. The effect of such elements on a carbon steel is to retard the decomposition of the Austenite, which means, for example, that the critical changes of a 0.30 per cent. carbon steel containing proportions of nickel and chromium are lower than the critical changes of a plain 0.30 per cent. carbon steel. The slow rate in the changes of structure of alloy steels explains the reason of their ability to harden in oil. Although the majority of alloy steels contain a comparatively small proportion of carbon, the hardening is primarily due to the carbides which are formed with the various alloys.

Nickel does not combine with carbon to form a carbide, but enters into complete solution with the ferrite. Nickel increases the tenacity and ductility of steel, even in the annealed condition, but due to the high cost, it is uneconomical to use nickel steels unless they are fully

heat treated. Nickel lowers the critical points of a steel, and at the same time considerably affects the rate of decomposition of the Austenite ; thus, a given sized piece of nickel steel, quenched in oil, will be hardened just as effectively as a plain carbon steel, of equal size, which has been quenched in water. This sluggishness in the decomposition of Austenite, when the nickel content is high, is the reason why such steels are termed " air hardening."

The effect of chromium upon the critical points is the reverse to that of nickel ; chromium raises the temperature at which the critical points occur, and therefore, a chromium steel must be heated to a higher temperature, if it is to be hardened, than is required for either a plain carbon steel, or nickel steel. Taken by itself, this effect of chromium should make it more difficult to harden, but it is found that chromium, like nickel, produces that sluggishness of decomposition so that, in reality, hardening can take place at a temperature equal to those of a plain carbon steel of equal carbon content. Chromium forms a very hard carbide with carbon, and any excess goes into solution with the ferrite.

The most common of alloy steels used are undoubtedly the nickel chrome variety. The combination of nickel and chromium with a plain carbon steel imparts the properties of each alloy. From the nickel content, toughness and ductility are obtained, and increased hardness of Cementite and Pearlite are due to the chromium carbide. Whereas in a plain carbon steel, hardness is obtained with loss of toughness, alloy steels, when suitably heat treated, will give a greater toughness with equalled hardness.

Manganese is present in all steels, but is not usually considered as an alloying element unless there is 0.9 per cent. present. Like chromium, it forms a carbide with carbon, and under certain conditions associates with Cementite, forming a carbide. For most purposes, 1.0 per cent. Manganese is considered the limited amount, and with this percentage low carbon steels appear to have a denser pearlitic structure than a low carbon steel containing less Manganese. This feature explains the reason of the increased toughness Manganese imparts. At five per cent. Manganese, the steel is exceedingly brittle and of no practical use, but in increasing the content up to 12 per cent. the brittleness disappears, and the tough, hardwearing steel known as Hadfield's Manganese steel, is formed. Manganese lowers the critical points.

Molybdenum is used in steel up to about 0.7 per cent. only, but has pronounced effects on the physical properties at even 0.25 per cent. Molybdenum promises to become one of the most useful alloys, but its field of usefulness is still to be extended. Steels containing molybdenum are not readily oveıheated, because of its effect of restricting crystal growth.

Vanadium is alloyed with steel between 0.10 per cent. and 0.25 per cent., and in tool steels between 0.5 per cent. and 1.00 per cent. It has the property of increasing depth hardening, which means that steels containing Vanadium are hardened more uniformly throughout their mass. Vanadium also restricts crystal growth, and hence is not easily overheated. It is generally alloyed with chromium, and such steels are extensively used for springs because of their high resistance to shock and fatigue.

The general effect of the various alloys is to promote increased physical properties, especially when heat-treated ; such treatment is varied according to the amounts of the various alloys present, but in the main the principles are the same as those used for heat treating plain carbon steels.

Case Hardening. For many purposes the engineer requires a material possessing a glass-hard wearing surface, but internally soft and tough, capable of withstanding shock and torsional stresses. By subjecting certain steels to the process of case hardening, these properties may be produced. The process consists of forming a high carbon layer on the outside of a soft steel, and then heat treating to harden the case, leaving the core soft. While the hardness of the case is important, it is necessary that the core possesses sufficient tenacity and toughness to compensate that lacking in the case.

Case-hardening steels range from the straight carbon type, which have approximately 0.15 per cent. carbon, to the three per cent. and five per cent. nickel steels which contain usually 0.12 per cent.-0.15 per cent. carbon. The nickel steels are used when torsional stresses are exceptional, such as in the automobile gear shaft, and where such stresses are not so excessive, the straight carbon type are generally used.

The operation of case-hardening depends, primarily, on the absorption of carbon when the steel is heated in contact with carbon-bearing materials above the upper critical temperature of the steel. The majority of carbonizing materials used are solids, which, at high temperatures, generate gases, principally carbon monoxide, and it is these gases which react with the surface of the steel, forming iron-carbide, which is Cementite.

The articles to be carbonised are packed in steel boxes with the carbonising material, and the lids luted with fire-clay to prevent the escape of the gases. The composition of the carbonizing materials is important, as much of the success of case-hardening depends upon the quality of the gases produced, and the rate at which they are generated from the material. Wood and animal charcoal, charred leather and petroleum coke form the basis of such materials ; various energizers in the form of alkaline carbonates are also mixed with the charcoal base.

The upper critical point of a 0.15 per cent. C. steel is 900-920 degrees C., and at this temperature the steel consists completely of Austenite, and in this state Cementite is soluble. Thus it can be understood that the Cementite, which is formed at the surface of the steel by the action of the carbonizing material, will diffuse into the underlying layer of steel. This diffusion would, if circumstances permitted, continue until its concentration was uniform throughout.

The rate of penetration of the Cementite depends on the temperature at which the operation is being carried out—the higher the temperature, the greater the rate of penetration. Similarly, the higher the temperature, the more rapid will be the formation of Cementite at the surface of the steel. The formation of the case is gradual, the carbon content being highest at the surface, decreasing until the case merges into the core.

In general carbonizing practice, the carbon content of the case does not exceed 1.20 per cent., which is reduced by subsequent grinding to 1.0 per cent.-0.9 per cent. C. Carbonizing temperature should never exceed 950 degrees C., otherwise there is a tendency for Cementite to be formed at the surface of the steel much quicker than it can diffuse, resulting in a high concentration of carbon in the case, which is the cause of cracking and the spalling or peeling of the case.

The depth of the case is an important factor, and varies according to the nature of the component ; 1/100 inch for light work, to as much as 15/100 inch for heavier work, is the usual practice in heat treating shops. For most practical purposes, a case depth of about 3/100 inch is satisfactory, and this can be obtained under normal working conditions at a temperature of 900-950 degrees C. in a period of four to five hours.

Carbonizing operations demand careful control if production is to be consistently uniform. Standardization of the carbonizing mixture is essential ; temperature should always be controlled by pyrometers, and in large production shops variations of temperature are recorded by graph, so that suitable adjustments of time or temperature may be made. The uniformity of temperature at all points within the furnace, the size and shape of the boxes and the position of the article in the box, are factors influencing the uniformity of the product.

Test pieces are usually placed within the box, and these act as a check upon the depth of the case, and, if satisfactory, the boxes are removed and allowed slowly to cool to atmospheric temperature before the work is removed. The structure at this stage is exceedingly coarse, due to the prolonged heating at high temperature.

The larger grains of the case compare with those of the core,

providing an interesting demonstration of the effect of carbon on the position of the critical temperature.

Increase in crystal size commences only after passing the upper critical point; carbon lowers the critical point, thus the critical temperature of the case, which is now a 1.2 per cent. steel, is much lower than that of the core, which is the original 0.15 per cent. steel; consequently the crystals of the case are much coarser than those of the core. It is therefore necessary for these two different structures to have different treatments, one to refine the core and another to refine and harden the case.

When the article is required for its hard surface only, it may be quenched in water, straight from the carbonizing box, but this method is generally modified by cooling in the box and then reheating and quenching at a temperature sufficiently high to refine and harden the case. The double treatment is adopted only to those parts which are subjected to stress, and consists of a quench from a high temperature suitable for refining the low carbon core, followed by a lower heating and quench, suitable for refining and hardening the case.

These operations are sometimes followed by a tempering operation at a lower heat, about 200 degrees C., which tends to relieve the strain set up between the case and core.

It is often necessary that some portion of the article must be left soft, e.g., the screwed portion of a shaft; this portion is covered, before packing, with an insulating compound which prevents the penetration of carbon. This compound, which is made in the form of a paste, consists of fireclay, sodium silicate, and borax. Copper plating is also used, and a film 1/1,000 inch thick will prevent any penetration of the carbon.

Of recent years the process called nitriding has gradually become a commercial reality. The fact that nitrogen had the effect of hardening steel has been known for many years. The first theory to be advanced on this subject was originally due to the apparent hardening process which took place in gun barrels, the nitrogen being introduced by the explosion of the gunpowder. The actual nitriding process of to-day is of a comparatively simple nature. The articles to be nitrided are thoroughly cleansed free of dirt and grease and placed in a special heat resisting steel box. The lid is then fixed so that the box is perfectly gas tight. Ammonia gas, which consists of one part nitrogen and three parts hydrogen, is then allowed to circulate through the box, which is enclosed in an electric furnace at a temperature of 500 degrees C. plus or minus five degrees C.

This heat is maintained for a time suitable to the depth of case required, ten hours producing a case of 4/1000 inch.

The nitriding process has many advantages over ordinary case hardening practice. The surface hardness is much greater, and the

full hardness is retained up to 500 degrees C., and even at 700 degrees C. the reduction of hardness is very small. The possibility of seizing owing to the lack of lubrication is therefore greatly minimised. On account of the comparatively low temperature at which the process is carried out, the risk of distortion is practically eliminated. The hardness is not induced by quenching, and consequently quenching cracks are unknown.

Nitriding demands the use of special steels which are called nitralloy, which may be understood to be a chromium aluminium alloy steel, graded by the carbon content which varies from 0.2 to 0.6 per cent. According to the physical properties required of the core, suitable heat treatment of the steel is done before the nitriding.

Brinell hardness (if possible to obtain) = 900 to 1,100.

Paper by S. Wood. Grad.I.P.E.

IN contributing to this talk on heat treatment, I have attempted to review the subject from the point of view of the production engineer, who, although he has not essentially the knowledge of the finer theories of heat treatment, should be familiar with the peculiarities of its results, and should also know to some extent the necessary methods of its procedure, and the difficulties experienced therein. Thus he may deal efficiently with probable snags encountered, or even suggest an alternative design.

Until about 1890, the subject of heat treatment of steel had attracted little scientific attention, and, strange as it may seem, the development of alloy steels had been in progress for several years before the significance of heat treatment was realised. Subsequently, the development in manufacture and heat treatment occurred concurrently as heat treatment is of highest importance in contributing to the superior qualities of the product, and only by so developing the potential properties can the benefits accruing from the use of alloy steels be justified with the increased cost.

To quote an example in practice where the use of alloy steel is justified, we may take the case of connecting rod bolts in heavy marine or Diesel engines. Here is required a material that will withstand shock and the reversal of stress under long periods of action. These conditions can be satisfied by using an alloy steel of a high impact figure, together with a reasonably high ductility, providing that the alloy has been correctly heat treated. The size of the bolt in alloy steel is much less than in carbon steel. This decrease in size of bolt will also be applicable to the cap itself, thus minimising the designed size of the rod, with the result of greatly decreasing the inertia effects and stresses due to weight. Also the con. rod being smaller in size calls for a smaller clearance space and so reduces the casing design with a saving in bulk material.

Many examples can be quoted where the size of structure is governed by the size of member subject to the greatest stress, and naturally, if this can be minimised, so can the bulk material, and alloy steels in these cases, as well as being a more satisfactory job for critically stressed parts, are cheaper in over all effect.

It may be said that the object of heat treatment is to secure a perfect diffusion of the carbon present, and a fine grained structure free from brittleness. In order to fix the best heat treatment, it is necessary to find the temperatures of the critical changes for each case, since the special alloying elements influence these temperatures and they also vary with the carbon content in plain steels. Also the

rate of cooling has to be taken into account. When all the constituents of the steel have passed into a state of solid solution, the greatest refinement of grain is obtained, but owing to inertia effects, it is necessary in practice to heat the steels a little above their critical ranges. Temperature control should be by pyrometer, and important factors are, the location in furnace, the type of fuel, and character of furnace gases, whether neutral reducing or oxidising, time of transference from the furnace to the quenching bath, and the temperature and nature of the quenching medium.

A most important feature of the effect of temperature on steel is the crystal size as revealed by the micro-structure of the quenched condition. At the correct hardening temperature, the grain size is extremely fine, and as the temperature of the steel is raised, the grain size becomes larger. An approximate temperature for a carbon steel at which the grain size is finest would be from 800 degrees to 900 degrees C. At this latter temperature the grain size is increasing and continues to increase up to 1200 degrees C., where there is a sudden enlargement as the burning range is reached. Here the steel is in an impossible condition and can only be utilised by remelting.

This leads to the advantage of heat treatment, for the grain or crystal size has the greatest effect on the physical strength of the steel, as will be seen later by reference to Izod figures. Thus we have the correct temperature for obtaining the most refined structure, and if quenched at this temperature, will give the maximum hardness, and a generally more homogeneous structure which can be relied upon under diverse conditions. But an important feature is that in inducing great hardness we have the advantage of being able to exchange the hardness for roughness by tempering.

Generally speaking, the extent to which a material can be improved by heat treatment depends on the extent to which it can be hardened in the first instance. There is, however, the importance of quenching to be considered. There is the time lag to be taken into account, and unless the quenching is more rapid than the rate of change of the structure, the material will not be uniform, and also a rapid quench where it can be effected is often the cause of warping or cracking. This leads to what is known as mass effect in plain carbon steels, where the rate of quenching must be very high in order to prevent transformation at the change point. Therefore plain carbon steels must be quenched in water to obtain the best results, and in the case of large masses the effect will not penetrate to the centre.

The advantages of alloy steels in this respect are apparent, for if a pure carbon steel bar of about one inch diameter was quenched in oil, the hardness induced would not be so much as if quenched in water. If, however, one per cent. of manganese was added, then by quenching in oil, the hardness induced would be almost a maximum,

the reason being that the manganese delays the rate at which the diffused constituents reappear as separate substances.

Nickel, in respect of showing the rate of transformation, is alloyed with steel, and also has other beneficial effects inasmuch as it increases the strength, ductility, and toughness, and greatly increases the ratio of elastic limit to maximum strength, generally rendering the steel more susceptible to heat treatment.

For case-hardening purposes, nickel is used to advantage, for it enables sufficient hardness to be induced by oil quenching, owing to the fact as pointed out above, and since it has the effect of lowering the change point and restricting the grain size at high temperature, it is not always necessary to have the refining treatment, as in the case of plain carbon case-hardening steels. Nickel also strengthens the core of case-hardened steels. On the other hand, it opposes the penetration slightly, making slower penetration than in plain carbon steel, although the graduation is more uniform.

I have mentioned nickel and manganese as an element which overcomes the difficulty of mass effect in plain steels, and along with nickel are chromium and molybdenum used singly or together as rendering steels more responsive to heat treatment, although I do not propose in the space of time to deal in particular with their singular properties. Before I deal with the varying physical properties produced in the types of steels mentioned, I shall digress for a while on the principal tests applied to steels in the workshop and laboratory.

Briefly, the tensile test, which is the most commonly known. This is more valuable as a laboratory test, and it enables such useful information to be obtained as the ratio of elastic limit to yield point, which cannot be obtained by any other test, but it is of course expensive to make, and the workshop method is to use a Brinell testing machine which, for practical purposes, gives satisfactory results.

Apparently, to define hardness is not simple. Hardness is usually associated with abrasion-resisting properties, but many curious anomalies occur, and we have the case of soft babbit metal providing an excellent example of the reverse of this law, and even cast-iron does not register such a high Brinell hardness number as hard steel, but is equally as good for normal bearing surfaces. Also manganese steel, which gives a fairly low Brinell number of 200 has excellent wear-resisting properties. Here it might also be mentioned that the Brinell number is not always an indication of machinability, since the above-mentioned steel is unmachinable at the number, whilst nickel steel or cast-iron of 230 Brinell is machinable. To get back to the original topic of hardness, it appears that, apart from a few exceptions such as mentioned, hardness is desirable in steels for wear-resisting properties, as well as for toughness.

Hardness is commonly defined as the resistance offered by a body to penetration, and the Brinell or Rockwell tests are direct applications of this. The method is that of applying a hardened steel ball into the surface to be tested, under the standard load. The diameter of the impression is measured by means of a microscope. The actual Brinell number is the load ÷ area of the spherical surface, and it is a fact that the Brinell number closely follows the ultimate strength of the material tested. The test was first introduced in 1900 by the Swedish metallurgist, and is now the currently accepted method for general use. Brinell first adopted as a hardness number the load ÷ the area of projection of the ball diameter. This was found, however, to give different readings on the same material with different loads, and the same ball, as the higher loads gave higher hardness numbers. The explanation of this is that the heavy loads have a work-hardening effect, due to the cold work done by the ball. To compensate for this, the Brinell number adopted was the load divided by the spherical area of the impression. This compensation is, however, only partial, and therefore the Brinell number is really an empirical rule.

In practice, it is used for checking steels in the normalized condition, as in the case of drop stampings, to detect excessive hardness before the machining operations, or lack of hardness, in which case, the article will be below the tensile specification. It is not used, however, for brittle materials, or hard steels in the hardened condition, as it operates above the elastic limit of most substances; also the deformation of the ball is more likely to occur in hard materials giving unreliable results.

For the harder variety of steels in the hard condition, the Rockwell test is more generally applied, owing to the employment of a diamond cone penetrator. The test is similar in principle to the Brinell. The method is that of forcing a hardened steel ball of $\frac{1}{16}$ inch diameter on a diamond cone into the specimen, but the load is applied in the following manner. A minor load of 10 kilograms is applied which firmly seats the ball on the specimen. At this point the indicator clock is set at zero. A major load of 100 kilograms is then applied, and as the indicator clock finger comes to rest, the major load is released. Here, with the release of the major load, the elasticity of the metal under test has been removed, and does not enter into the reading. Finally, with the minor load in position, the Rockwell reading is taken from the dial.

The readings taken with a $\frac{1}{8}$ inch diameter ball are called Rockwell B scale, to differentiate them from those taken with a diamond cone penetrator.

As Rockwell hardness numbers are based on the difference between depth of penetration at major and minor loads, it is evident that the greater this difference, the softer will be the material, and the

less the number. The machine is arranged to read directly from the dial. For hard metals, the diamond cone penetrator is the more accurate, while the ball is more accurate for the soft metals.

Although similar, the Rockwell test does not measure properties identical with the Brinell test, as the Brinell takes effect through a range of depth greater than the Rockwell, showing different results in a non-uniform material, such as cold drawn bar.

The Scleroscope is another type of instrument for hardness measuring, but depends upon a different principle from the others mentioned. Hardness is taken to be proportional to the rebound of a small hammer, which is allowed to fall by its own weight upon the surface of the material. The hammer takes the form of a cylindrical plunger, the lower end of which is pointed and fitted with a diamond of a standard size. The hammer is guided in a vertical tube of glass at the top of which it is held in position with a catch. The operation of the hammer is by means of rubber bulbs, one to release and the other to engage the hammer at the top of the stroke. The degree of hardness is given by the height of rebound of the hammer, which is read off on a scale graduated on the glass tube. The scale is an arbitrary one on which hard steel has a value of 100.

The consideration of the Izod test brings us to a service requirement which no other physical test supplies, and that is toughness. For an illustration, a mild steel casting in the unannealed condition may register a maximum stress and elongation as great as a forging of the same composition, but if a notched bar of each material is placed in a vice, it can be shown that the casting will break off under a sharp blow, whilst the forged bar will bend over, perhaps without cracking. This will serve to show the need of a test connected to the probable conditions of working stress, and the Izod test is an application of the above.

In principle, the Izod test represents the breaking of a prepared and notched specimen by means of a pendulum hammer, swinging with a determined blow, the energy required to destruct being deduced from the initial energy and remaining energy after the blow.

For accurate results it is essential for the material to be free from defects in steel manufacture, such as seams and laps, or a low Izod figure will be wrongly attributed to the condition of the material itself, rather than to the defects in manufacture. If the material under test is of a soft condition, there will be a deformation of the material around the fracture; on the other hand, a hard material will crack without deformation, so the impact figure includes the energy required to start and extend the crack and to deform the material around the fracture.

Low impact figures are associated with extreme brittleness, or in materials annealed incorrectly, or tempered incorrectly. To decide

whether an impact figure is good or bad, the other mechanical properties must be taken into account. If the steel has an Izod figure of 30 feet lbs. and a yield of 100 tons, it would be extremely good, but if with a maximum stress of 20 or 30 tons it would be very poor.

To deal with the physical aspect of heat treated alloy steels brings us to what is required as an efficient structural steel. The demands are for high strength consistent with toughness and ductility. This, in the case of plain carbon steels, is limited, as the hardness which is consistent with high tensile strength is accompanied by a low elastic limit or low ductility. To show the effect of nickel as an alloy inducing maximum toughness, the following example may be quoted.

FIG. I.

	Carbon	Silicon	Mang.	Nickel
Carbon steel	.33	.15	.63	Nil
Nickel steel	.33	.13	.63	3.28

FIG. 2.
PHYSICAL PROPERTIES.

	Y.P.	M.S.	E. Percent.	R.A. Percent.	Izod.
Carbon steel ...	—	52.8	16	43.2	10 & 11
Nickel steel ...	43.2	52.9	25	64.5	100 & 104

The comparison is between a plain carbon and a nickel steel. The carbon steel is in the quenched condition. The nickel steel after quenching would have a tensile strength of about 100 tons, but if tempered to about the same ultimate stress as the carbon steel, the Izod figure is extremely higher. This shows the ductility of nickel steel consistent with strength.

Another steel responsive to heat treatment is the 100 ton nickel chromium, carbon 34, manganese .65, nickel 3.30, chromium .84. By quenching in oil or, in the case of small sections, air quenching is sufficient to induce a maximum strength of 120 tons with a yield point of 110, but is accompanied in this state by a low Izod figure of 10 feet lbs., as might be expected. By tempering the hardened pieces at varying temperatures, the hardness is decreased, but giving the other valuable properties high ductility and Izod figures. As will be seen from a graph of the effect of varying the tempering temperature, there is a large range of these properties ; a maximum Izod figure and ductility is obtained by tempering at 650 degrees C. for the particular steel. This naturally occurs with the lowest yield point at 50 tons. Thus from this one steel several states or conditions can be obtained to suit diverse needs. There is, however, a point of interest in the tempering operation to notice with these nickel

chromium steels, which occurs at the tempering temperature of 300 degrees C. Here the Izod figure makes a sudden dip, and the phenomenon is known as temper brittleness, occurring by cooling through the range 325 degrees to 400 degrees C. This can be obviated in practice by cooling in water or oil after tempering, or, if rapid cooling is not practicable, an alternative is to use a steel containing a small amount of molybdenum.

The effect of this is clearly shown in the following figures which relate to a crankshaft steel which had been slowly cooled after tempering instead of quenching in water.

Fig. 3.

In the first condition :

Y.P.	MAX.S	E. Percent.	R.A. Percent.	Izod.
45	53.7	21	55.8	2 & 3 feet lbs.

In the second condition, after reheating to tempering temperature and quenching in water :

Y.P.	MAX.S	E. Percent.	R.A. Percent.	Izod.
45.6	52.4	21	59.3	76 & 77 feet lbs.

It is of note that the tensile properties are almost identical, but the marked improvement in the Izod figure illustrates the importance of quenching after tempering.

In conclusion, I add that I have found myself endorsing heat treatment only from the point of view of the alloy steels. At the same time it undoubtedly pays to give attention to the heat treatment of the plain carbon range where they can be employed, for by so doing their range of usefulness is greatly increased. Secondly, that heat treatment itself is not the only feature contributing to the final quality, as much will depend upon the manufacture of the raw material. Steels of the same composition vary with the supplier. Finally, I make no pretence of having covered all the ground, even from the point of view which I have taken up, and so I invite criticisms upon points which I have not enumerated as well as those which I have mentioned.

Discussion

Mr. D. A. Tilt (Chairman, Birmingham Graduate Section) who presided opened a very animated discussion which was taken part in by numerous graduates and visitors. Mr. McNab, he said, had told them that heat treatment consisted in getting a piece of steel with a few crystals in it ; on heating it, these started running round and round, and in the case of hardening, it was hoped, by quenching at a certain temperature, to catch them where they ought to be, but in most cases of hardening, this point was missed, and the desired results were not obtained. This seemed to him a very unsatisfactory method and wanted going into further ! He also inquired how long a time was spent over the test piece which was taken out of the furnace to determine the correct hardness of the material, because it seemed to him that if it had to go through various tests such as the Brinell hardness test, the bulk left behind in the furnace would go on to another temperature.

Mr. McNab said that various structures were obtained by various temperatures the material was treated to. In order to make the process clear, he compared the different crystals constituting steel to two colours—red and yellow—and explained that, after heating up to a certain temperature (the upper critical point) the two different types of crystals (or colours) merged and became " Austenite " (or orange) and whilst the temperature of the steel remained at the upper critical temperature, the Austenite condition remained. This condition, however, could only be absolutely retained if a high carbon steel were quenched in ice water. It was necessary, in practice, to heat, above the upper critical range, if the structure (of the upper critical temperature) is desired because the rate of quenching is generally slow enough to enable a change or partial change of structure to take place. With regard to test pieces, Mr. McNab said that his remarks had been concerned with test pieces in carbonizing a series of main shafts. Anyone passing through the hardening shop would see small pieces of wire sticking out of the boxes in the furnaces, and tied to those pieces of wire were the test pieces. The test piece was put in the box and the ordinary time and temperature of heating of that particular job, was proceeded with, after which the piece would be withdrawn. The person in charge of the firing would then come along, quench it, break it off, and take it to the foreman. The foreman would look at it, and if it was satisfactory, the box would be withdrawn. Otherwise he might decide to give it another half-hour or hour carbonizing. Actually the case was very easily seen when a fracture was made, in in the coarse state.

PROGRESSING OF WORK IN THE SHOPS.

Paper presented to the Institution, Western Section, by C. Shread.

WHEN commencing this paper, I had not realised to what a large extent "progressing in the shop" has, in the last few years, been eliminated at the Austin works. Therefore, I am afraid that it devolves upon me not to try to tell you how to progress the shops, but rather to try and give you some idea of the methods formulated and improved upon from time to time to enable the output required to be obtained with a *minimum* of progress work, as such, attained some years ago.

I remember when the Austin works and output was but a tithe of its present magnitude, but even then the machine shop progress staff exceeded the present staff. The smallness of the batches caused multiplicity of chits, and figuratively speaking, an army of clerks posting into progress ledgers, which, incidentally, were never up-to-date. Of course, we had no line production then; instead the different classes of machines were grouped—Capstans, Gisholts, Jones & Lamson's milling machines, etc.—each, so to speak, were a law unto themselves. This condition, you will readily appreciate, entailed a vast amount of movement of material, as well as the resultant clerical recording of same.

Then there were instances of machines being overloaded, whilst others were not occupied to their full capacity, causing breaking down and setting up for small batches, thus necessitating a progress man to continually prime, or persuade, or get on the right side of the foreman, with a view to a bit of wangling being done. This sort of thing became impossible when output was spoken of with a capital "O."

I do not want you to take any subsequent remarks as dogma or as a description of the perfect system, or even a system to be copied, but I feel sure that there are points which will be of interest to anyone engaged in large production, and I hope, to those connected with concerns handling more varied products in smaller quantities.

A point I would like to emphasize is that future output is budgetted for at a weekly programme rate, which it is not necessary, on the whole, to alter to any great extent. Sanctions for purchase of material usually cover about fourteen to sixteen weeks, so that

Bristol, March 9th, 1934.

any rise or fall of programme can be handled fairly readily, and I shall show later how the material flow is adjusted to suit any fluctuation.

The following are the departments and their functions, apart from the manufacturing shops, which, to satisfy the requirements of the sales and the board, work as a team.

(1) Designs Office : When designs are settled, each component is given a piece number, blue prints are issued simultaneously to the production office, efficiency department, jig and tools drawing office, and inspection department.

(2) Production Department : Issues all orders for producing cars in conjunction with the budgetted programme. It is responsible for the supply of all material, and the movement or progressing of that material from its receipt on the ground to the finished product, involving buying office, receiving deck, traffic department, all stores departments, progress, and manufacturing shops.

(3) Efficiency Department : Plan and issue all operation layouts, keeping a check on the capacity of the plant as extra output is desired or new components are designed, and are responsible for ordering all necessary plant.

(4) Jig and Tool Drawing Office and Tool Room : Are responsible for the production of all jigs and tools, also the demonstration of these in accordance with the official layout.

(5) Inspection Department : Carry out the inspection of all material received, and all operations subsequently performed, and provide the necessary staff throughout the shops to avoid adding any more time to the actual production time than is necessary, in conformity, of course, with a standard of finish.

I will now explain briefly the routine between these departments. Upon receipt of designs, the production department apply to the efficiency for a route or allocation, showing the source of material, and the various manufacturing departments whose obligation it will be to handle individual components. This having been supplied, multiple copies are distributed to all concerned.

The types of cars for which the components are required are stated, so that in conjunction with the production orders already issued and the budgetted programme, the various departments are advised of their obligations.

The buyers are then instructed as to supplies of material from outside sources. Efficiency follow these allocations with detailed operation layouts showing the actual machines on which the operations are to be done, and the time allowed for each operation. The jig and tool department, in co-operation with the efficiency, then get busy with the supplying of the necessary equipment.

Perhaps you are thinking that I have not yet told you much about the progress in the shop, but if you will be patient, I think

you will agree that the whole of the operations, both clerical and otherwise, from designs onwards, are devised to make the progress of the work through the shops practically automatic, and that is the point I wish to make.

In order to control effectively and ensure the required production, it is necessary that complete and up-to-date records should be available in a central office, in this particular instance the main production office. Years ago, these records were compiled, or rather, endeavours were made to compile them, by hand. As business expanded and output increased, however, the mass of detail to be handled became so large that, despite the incessant slogging away by the staff, the essential information could never be kept up-to-date. Further, the staff compiling the records never had a sufficiently complete picture of the position before them. It was therefore decided to adopt a mechanical form of recording and tabulating the movements of material, etc., which is now done by the use of a punched card. The functioning of this card I will explain later on. I will now run through the organisation from a production and progress point of view, in the hope of making the point already referred to.

The drawing office requisition is issued together with drawings when the design is settled. Upon its receipt by production office, the allocation sheet is made out, leaving, of course, the route column blank. This is submitted to the efficiency department, who fill in the details of the route, and return it to main production office. At the same time, a copy is sent to the drawing office, where blue prints are made and distributed to the manufacturing departments concerned. The efficiency then issue the layout form, showing the operations, machines, tools and jigs, and the time allowed for the various operations. The production man places an order with the buyers to cover quantities already sanctioned, as per the main production chart. At this point, I would mention that in the main all records are kept, and quantities referred to, in terms of chassis numbers.

Every chassis turned off the erecting line is given a consecutive number, and therefore by this method one can look forward or compare records, not only in terms of quantities, but also in terms of time—say, weeks or months—or, for that matter, in days or hours.

On the left-hand side of the chart are the numbers of the chassis sanctioned to be built. Along the bottom are weekly dates. The graph lines reading from left to right denote approximately the dates when stamping material should be available. The next shows the ideal time when stampings are required, but to enable stamp

shop to produce in economic quantities, or according to the life of dies, and further, the fact that certain components require heat treatment, etc., whereas others when stamped are ready for machining, a period of nine weeks is allowed.

The next is foundry and bought out rough line. This allows three weeks in which to bring through material according to lengths of manufacturing time, bulk, etc.

Then the machining and ordered out finished line allows five weeks for machining, and the assembly of power units, axles, sterring, etc., ready for the erection of chassis to programme.

This chart, having been made out in advance, is naturally not cast-iron, so that, according to the requirements of the sales, a detailed chassis erecting programme is issued weekly, and any of the larger or more expensive components are advanced or retarded accordingly, but, owing to careful forethought, these graphs over a period work out fairly accurately.

The next step in production is the placing of orders by the buyer. The order form gives quantity and rate of delivery, and also a control number. Now, this control number is the first step in our automatic progress.

Every store and department is given a separate control. The first three figures denote the number of the store or department, and the fourth indicates whether the material is productive or non-productive. The fifth and sixth indicate pre-arranged divisions of the various components sent to stores, and is used for accounting purposes only. Copies of the orders are sent to receiving department, the stores concerned, and the accounting departments. The receiving department, therefore, on receipt of material, and after inspection, know the location of the point to which it is to be sent.

Upon receipt of material, a reception note is made out and duplicated copies are sent to the various departments. The Inspection copy accompanies the material through inspection and rejections, if any, are noted, the stores in this way being advised of the net result of the delivery. The rejections are returned to the suppliers, and debited to them in every case.

A preliminary note is used to advise stores immediately upon receipt and before inspection, so that, should the necessity arise, they can ask for preferential treatment by the inspectors. In the case of stamping and machining bar and sheet metal, each delivery is bonded, and a material test is made by the inspection department in every case, thus avoiding danger of future hold-up during progress through the shops. In the case of other material, frequent tests are made at the discretion of the inspection. Electrical equipment is given 100 per cent. test before being released.

We will now deal with material which has to be machined. Every machine, whether single purpose or otherwise, is allocated

sufficient work to keep it fully occupied, so therefore the size of batches and frequency of same can be predetermined. Route cards for these batches are made out in advance by the progress man, and deposited with the storeman, who delivers the material to the machine in the correct rotation. These route cards show the part number and description of the material, a consecutive batch number and the batch quantity, and other information deemed necessary. On the reverse side of the card abbreviated descriptions of the operations and the machine numbers allocated are written, as per official layout.

The operator, when ready to commence, presents the route card to the section time clock office, and is clocked on the job, being given a clock card which eventually is used as a basis for payment of wages.

Inspection takes place in nearly all cases coincident with the completion of operation; thus enabling the material to flow from operation to operation without any delay. This system brings about a condition of automatic progress which eliminates the necessity of progress men except in instances which I will explain. These exceptions are due to the abnormal growth of the organisation.

The original works consisted of one block of shops now known as the South Works, two further blocks having been added, namely, the North and West Works.

The movement of material which consists mainly of complete assembled units such as engines, gearboxes, trimmed bodies, etc., naturally calls for someone above the station of a labourer to control despatch and reception of such material.

The North Works handles mostly the engines and gearboxes, and also houses the automatic bar machining section. This section, on account of the setting-up of tools, works on an economic quantity basis, and of course, with due regard to sanctions; and possesses a store where the various components are placed when machined, and from which they are despatched to other departments in weekly batches according to programme. A fleet of lorries is employed in transporting the products to the South Works.

The West Works is solely occupied in the production of finished bodies ready for mounting on to the chassis. The bodies, when painted and trimmed, are despatched to the South Works on a train of slave-bogies, which is towed by a lorry to the mounting lines, where the appropriate chassis simultaneously arrives. This is achieved by the use of the Creed Teleprinter Tape Machine. At a point on the body building line a transmitter is installed. Upon arrival of the body at this point, a chassis number is allocated to the body, and this, together with the body number, type, colour and any special information such as items deviating

from standard, is telegraphed to a receiver at the chassis line. The necessary chassis frame is then laid on the track, and passes through its operations to completion. It is then sent to the mounting shop to meet the body, all operations having been timed to make this possible. When considering the distance between the West Works and the mounting shop—quite half-a-mile—the advantage of the teleprinter will be appreciated.

In the South Works we have a press shop, where the mudwings, petrol tanks and the numerous other pressed sheet metal parts are manufactured.

Many of the parts require enamelling. In the case of mudwings, these are placed direct into an automatic carrier enamelling plant, where they pass through an enamel bath and a drying chamber without handling, except to load at one end, and unload at the other. As they are unloaded, they are hung on travelling carrier, which deposits them at a point on the chassis erecting line, where they are fitted to the chassis—another example of the elimination of progressing.

Other products requiring to be enamelled are transported to a plant situated near the erecting line, and are passed through wherever possible to weekly programme.

Other small pressings which are made in larger economic quantities are passed into finished stores, and from there are issued in appropriate quantities with other fittings to the assembly benches. The pressings which do not require enamelling are sent straight into finished stores, and issued in a like manner.

In the case of the seven h.p. erecting, the presses for making the various members of the chassis frame are situated at the beginning of the line ; these, when assembled, are put through an enamelling and drying stove direct to the erecting track, where they are numbered in rotation, in accordance with the teleprinted instructions.

Sub-assemblies, outside the range of engines, gearboxes and axles, are dealt with adjacent to the point where they are fitted to the chassis, the machine tool section for dealing with the necessary components abutting on the assembly benches, thus enabling the work to flow through with a minimum of movement or the need of progressing.

Components which are dealt with by finished stores, such as bought cut finished parts (nuts, bolts, washers and the like), are issued in the following manner :

Of course, an efficiency layout is in existence for all assembly operations. These layouts show the part number and description of the component or components to be assembled together at each operation, as well as the time allowed, etc. From them

are made out material issue vouchers for parts handled by finished stores, showing the part number, description and number off required per assembly. These vouchers are issued by the head storekeeper to the storemen with instructions to issue so many sets, say 25, 50 or 100, in accordance with programme requirements or the bulk of material. The issues being made in sets naturally cover so many chassis, and the number of the chassis covered by the previous issue having been recorded, a new chassis figure is arrived at. The number of sets required by the shops in advance has been fixed by experience and agreement, and of course, is occasionally altered to suit programme requirements.

The South Works also houses the hardening and heat treatment shop, the problem of performing this work in line production not having yet been solved. Here are handled stampings before machining, as well as machine parts requiring carbonising, decarbonising and hardening-off.

I will explain how the former are sent through from the stamp shop with practically no progressing.

After having been stamped in economic quantities, as previously mentioned, they are settled and passed into a stillage, or clearing house. From here, according to bulk and programme, they are put on to a conveyor which carries them to an automatic pickling plant, through which they pass to the rough inspection. Those not requiring any heat treatment are sent, after inspection, into rough stores, the others being transported a few yards into the hardening shop for treatment to specification. After treatment, they are returned to inspection for Brinell test, etc., and then to stores.

In the case of the components to be treated after or during machining, some supervision is required, as components are sent in from many points both in South and North Works, and, in the majority of cases, a decarbonising operation is necessary. To facilitate this latter, however, a machine section is laid down for this immediately adjoining the hardening shop, thus entailing transport for a few yards. After hardening-off, the parts are sent, usually for grinding, to a point as near as possible to where they will require to be assembled.

Wherever possible, advantage is taken of conveyors, not only as a means of feeding the rough material to the shops, but also on the machine sections themselves. For instance, crank-cases, gear-boxes, and flywheels are loaded on to gravity roller conveyors inside the stores, and gravitate to the first operation machine, and in some cases along the machine line to the final operation to a point within lifting reach of the assemblers.

In the case of front and rear axles and gearboxes, the machined components flow along to a travelling assembly track. At the end of this they are put through running-in fixtures and tested for quietness and brake efficiency, and then on another conveyor to the chassis erecting shop, through an enamelling booth to a drying stove, where they are conveyed to a point on the chassis erecting line at which they are required.

Engines are assembled on roller tracks, enabling them to be pushed from operation to operation to finish on a conveyor which takes them to the test house. Road wheels are fitted with tyres and conveyed by gravity a matter of seventy yards to the chassis line.

Another notable instance is the body painting track. Bodies are slung on this track, and on an average are continually on the move for fifteen hours, passing through spraying booths and drying stoves, finally emerging finished ready for trimming, glazing, etc.

The radiator shop is self-contained, having its own presses, crimping machines, etc., and here every advantage is taken of travelling conveyors. A very complete conveyor system is also installed in the polishing and plating shop. As the components are polished, they are hung on a conveyor running to the plating plant, which is automatic. Here they are put on specially designed hooks to suit, and are taken through the various solution and washing baths to emerge finished.

The method of valve production serves as another example of automatic progress. Doubtless it is well known to you that the old method was by forging in heading machines, finishing by turning and grinding between centres. The new method adopted is by the hydraulic upsetting process. Drawn bar 1/64 inch larger in diameter than the finished valve stem is used, and is reduced by centreless grinding to within a few thousandths of the finished size. The stock is clamped in a device which forms one electrode, and an hydrualic ram forces the end of the stock against an anvil face which forms the other electrode. Current is now passed through the bar, and when necessary temperature and pressure is attained, the desired upset is formed. The piece is immediately transferred by the operator, without re-heating, to a screw press, which finish-forms the valve head, including the screwdriver slot, with a practically negligible flash. Subsequent heat treatment has been found unnecessary. The valves are then placed in chutes, and gravitate to the grinding machines. Only three grinding operations are necessary, after which the end is faced off to length and formed for the cotter on a small facing lathe. The time taken from drawn bar to finished valve is three minutes, and roughly 14,000 valves per week are made.

I have already mentioned the main production office, where records are required to enable the production clerks to follow the movements of components from the inception of their instructions to the buyers. Mention has also been made of a punched card, and I shall now explain the use of this.

It is a thin, flexible card, into which information is transferred by means of perforated holes, and forms the basis of the well-known Powers-Samas system. Each hole represents a specific fact, and each card, when punched, contains the particulars relating to one transaction or movement of material. Once cards are punched, they become permanent records, which can be mechanically sorted, printed, added or subtracted. The cards are punched by girls on a machine similar to a typewriter, which prints the information on the top of the card as well as punching the holes. The sorting is done on a machine which sorts the cards into numerical order, and at the same time brings together all the cards of the same number or description. After sorting, the cards are passed through a tabulator, which translates the information contained and prints the result on appropriate stationery.

To make the best use of this system, it was deemed necessary to alter the whole of our component part or piece numbers, a big task, seeing that production could not be interfered with, but one which was successfully carried out. Four columns on the card were reserved for the actual piece number of the component. This gave a range of 9,999 numbers.

The chassis was then divided into the main assembly units, each being allocated a block of numbers, as follows :

Engine	1—3000
Gearbox	3001—4000
Front axle	4001—5000
Frame and details ...	5001—6000
Steering	6001—7000
Rear axle	7001—8000
Wheels and details...	8001—8500

thus leaving 1,500 spare numbers.

These divisions are constant, whatever the type of chassis, and therefore all concerned, upon seeing a piece number, know to which part of the chassis it belongs, and this has been invaluable to progress. A further two columns were utilised for a code prefix to the piece number, providing a range of 90 prefixes. These were allotted to the various types of chassis, such as 1A for the seven h.p., 1B for the 12 h.p., and so on.

These prefixes, in conjunction with the piece numbers, therefore indicate the type of chassis and the part of the chassis to which any component belongs. For instance, 1A300 would represent

a seven h.p. engine component, and say 1B4002 a 12 h.p. front axle part. Provision is made for the material source, such as B.R. for rough material bought from outside firms, B.F. for bought finished, F.Y. covers our own foundry, and so on, enabling the punched cards dealing with these various obligations to be sorted and tabulated at will.

The number off per set is also catered for. We then have five fields in which to collate our figures into terms of chassis numbers. The first one gives position of the buying order, and is made up by punching a card for each order, as placed, this information being taken from a copy of the buying order, after having been edited into sets.

The next shows the material received, obtained from the production copy of the deck reception note. The next field shows deliveries to stores, and is taken from the inspection copy of the deck reception note, after certification, and upon delivery into stores.

From this point onwards, every movement of material from one department to another is recorded on a Lamson Paragon quadruple note. The rough stores, therefore, upon issuing a batch of material, make one of these notes out showing the number of sets and from the production copy we get our issue figure. One copy is retained by the issuing store, another accompanies the goods, and the fourth is reserved for cost office use.

Where applicable, the shops do the same thing when delivering machined parts to finished stores, and this completes our last field. These paragon notes are collected at very frequent intervals, and delivered to the powers installation, where the necessary cards are punched during the day by girls, and stacked in convenient trays in readiness for the night shift. The cards are sorted and tabulated during the night, so that at eight o'clock each morning the position at 5-30 p.m. the previous day is available.

You will see that so far our operations have been in the nature of additions, but we get losses to production through various causes, such as scrap, services requirements and issues of material for purposes other than the erection of chassis. These losses are taken care of by punching substraction card from information supplied by inspection and stores, so that an effective available figure is reached. The consecutive chassis number built at the end of each day being known, the position of material is readily seen.

The tabulation sheet naturally throws up the lowest figures first. A minimum issue figure is arrived at, so that it is an easy matter for the production clerk to deal with those items showing less than the minimum figure.

You will notice that I mention a night shift. This consists of

a few young men and is the key to the success of the scheme, and the enabling of up-to-date information being produced. It is impossible for the girls to punch cards for transactions taking place immediately prior to their knocking-off time, therefore the information not punched by them is taken up by the night shift and completed ready for sorting and tabulating, as before mentioned.

A frequent question asked is "What happens if the punch operator makes a mistake in transferring the information from the Paragon note to the card?" Well, whatever information is offered to the tabulator, it is accepted, and in the early days of the adoption of the system, a fair amount of trouble was experienced. To obviate this, a section of the staff was set aside for checking. As the cards were punched, they were tabulated, the printed tabulation being then checked against the original Paragon note. Even then, errors crept through, but at last, a mechanical method was devised. The holes punched in the card are perfectly round, and the operator, after punching, places both the note and card together. These are then transferred to a separate set of punchers, who repeat the operation, but in this case, the punches are offset, and elongate the existing hole. The cards are then placed in a verifying machine, and passed through very rapidly.

Now, should any card still retain a round hole, this machine senses it, and a coloured slave card is flung on top of the offending punched card. Any of these can then very readily be taken out and corrected. This method has proved to be practically 100 per cent. efficient. The only way in which wrong information can get through is by the second puncher repeating an error made by the first one, but I cannot remember this to have happened.

Before closing, I would like to refer to a condition which is essential to the uninterrupted progress of machined components, and that is the provision of consumable tools, drills, reamers, taps, cutters and so on, in the shortest possible time after breakage or wear necessitates a replacement. The main tool store is situated in the tool room, and in each manufacturing shop is a sub-store. a very careful record is kept of the usage, and from this a minimum stock is fixed for each store, and is replenished daily, as required. These sub-stores, therefore, enable the setter-up or operator to obtain necessary replacements with the least possible delay.

In a like manner, consumable stores such as rag, wipers, greases, suds, brushes, etc., are dealt with, thus avoiding waste of time which, until the adoption of this methods, was considerable.

Discussion.

Mr. Wilson: What is your percentage of progress staff to production staff? How do you deal with drawing office change of design? With regard to conveyors going through machine shop to assembly bed, does that mean there is no inspection and that parts are not passed through the finished stores?

Mr. Shread: The percentage of progress staff as compared with operators—1,500 to 2,000 operators in one shop to one progress man in each shop. Progress labourers, where necessary, load lorries or unload them or run material out on trucks to be dealt with. With regard to drawing office changes in design. Drawing office changes at the Austin works—if they entail big alterations, such as jigs, etc.—are dealt with or a decision is come to by a production meeting held under the chairmanship of the works director. Sometimes we reply to the drawing office that the alteration cannot be made until existing material is used up. With regard to conveyors, where operations are performed on moving conveyors, the inspection takes place coincidentally with the operations performed, e.g., in the case of front and rear axles—these are conveyed to a running-in fixture and inspected there, when they are given a test for brake efficiency and also for quietness, then placed on travelling conveyor and travel to enamel plant, sprayed, dried, and dropped off. In the case of engines, these are inspected as they go along the rails.

Mr. Kenworthy: Would your system operate in smaller works? Or is it only applicable to line production? How much inspection takes place during the machining of components? What happens when a large batch of components are scrapped; how do you pick up? You mentioned that hold-up time is allowed in calculations for all operations—is time also allowed for inspection of parts? With regard to the numbering system for components used in the Austin works, this is not quite clear to me, and I should like an example. Do the route cards get into a very bad condition when passing through the shops?

Mr. Shread: With regard to large batches of scrap, inspection in our works takes place at the same time as the operation is performed, and this obviates large batches of scrap. Large batches of scrap might occur if the setter-up makes a mistake, and in this case overtime would have to be worked to make up. Generally speaking, we do not get large batches of scrap, and conditions are such that information is collated and we only advise people concerned once a month. The point at which inspection takes place is definitely laid down in the efficiency department's lay-out;

this might be one, two or three operations and then inspection, or in the case of a component which has to be machined before carbonisation, inspection takes place before machining, after carbonisation, after hardening, and then after grinding. With regard to the numbering system for components used in our works, the sheets supplied give examples of piece numbering. This system works very well indeed, and by glancing at the number we can tell instantly to what part of the car the relative component belongs. With regard to the question of the route card, those used in our works are of very stiff material, and as they do not travel very far they do not get seriously damaged or dirty.

Mr. Organ: In the case of a serious hold-up taking place—for example, a hold-up on crankshafts—the cards sent through to the department where the recoreds are tabulated would be of no use because the relative parts in the shops are no good for production, further, the parts going through for a particular engine would have to be retarded because no crankshafts were available. How is this position adjusted?

Mr. Shread: This condition does not very often arise. A break-down on crankshafts would be so very serious that everyone from the managing director downwards would be on the move. If material had to be withdrawn, it would be withdrawn through the inspection department, and record of the scrap would be passed through to the records department, and a special subtraction card is used in the tabulating machine which automatically reduces the figures. If this condition did occur, a policy would be fixed by a conference.

Mr. Foster: Will you please explain more clearly the functions of the efficiency department as compared with the inspection department?

Mr. Shread: Efficiency department would be called by many firms the rate-fixing department. They also decide methods of manufacture. If a machine is not available for a certain operation, one is ordered by the efficiency department. They take the machines to the jobs, not the jobs to the machines. The jig and tool drawing office is supplied with the lay-out and they supply the drawings.

Mr. Attwood: Does the efficiency department work in close contact with the jig office?

Mr. Shread: When models are changed over, a policy is laid down. Time limits are fixed for each depatrment. Efficiency department to produce lay-out by a certain date, jig and tool drawing office to produce drawings by a certain date after receipt of lay-out, tool room notified to produce jigs and tools by a certain date after receipt of drawings.

Mr. Saville: With regard to heat treatment, do parts follow the usual route?

Mr. Shread: We have not yet been able to do hardening in the production line. The production line is broken by sending parts from machine shop to hardening shop, and then they are returned to the production line. This does not break up production, as time is allowed for this.

Mr. Milton: Are jigs designed to meet rate-fixers' times?

Mr. Shread: Yes.

Mr. Attwood: When jigs have to be changed in production, are duplicate jigs kept in stock?

Mr. Shread: Duplicate jigs are kept where necessary.

Mr. Attwood: Is there any set time for jigs to be replaced? Is there any hold-up in production line?

Mr. Shread: Inspector reports if defects occur in a certain section, and then a new jig is supplied. A certain amount of time is allowed for hold-ups.

Mr. Organ: Does the efficiency department get instances of overloading certain machines and upsetting balance?

Mr. Shread: This very rarely happens. Should it occur, the shop foreman reports to the superintendent who refers back to the efficiency department for more machines. This would be very rare, as we budget beforehand, and the machines are provided before the work is offered to the shops.

Mr. Foster: Are there time limits fixed for work passing through the main view room?

Mr. Shread: We have no main view room. All viewing is done on the sections as work passes through. There is a view room on the receiving deck for finished parts bought from outside.

Mr. Higgins: What happens when machinery breaks down? Do you stock machine tools?

Mr. Shread: Of course, we cannot keep spare machines, but some reconditioned machines might be carried in stock. Every machine is kept under supervision, and every week-end of the year repairs are being carried out to machinery.